33.3: Small-Area Black Luminance Measurements on White Screen Using Replica Masks

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Abstract

Luminance measurements of small areas of black pixels on white-screen backgrounds are often used as metrics in display measurements, such as character-stroke contrasts or deep modulation transfer functions. Serious errors may be made in measurements and subsequent ergonomic conclusions if glare contributions of the measurement are not considered. We show a simple method for accounting for glare corruption of luminance measurements by using replica masks.

Introduction

Measuring black luminance on a white background can be quite difficult due mainly to the contribution of veiling glare. Glare results from many sources: light outside the field-of-view of the light-measuring device (LMD) scattering and reflecting at the lens surfaces; glass imperfections; dust and dirt on the lens surfaces; the barrel, iris, and other mechanical parts of the lens; and reflections between lens surfaces. This glare has been recognized for some time [1], but to our knowledge, it has not been addressed in the implementation of routine display measurements. For large-area black luminance, a glossy black cone can be used to minimize the effect of the glare [2]. However, if the cone aperture size is small (less than 5 mm), then the cone can interfere with the measurement. Reflection and scattering off the edge of the hole into the LMD or back onto the surface of the display can contribute to the stray light. Therefore, another method is needed to obtain these small-area measurements.

Significance

Small-area black luminance measurements and conformance specifications appear in display-measurement standards. The desire for a metric that is based upon actual display tasks drives these measurements. Such applications include text and small symbol recognition. However, because of veiling glare corruption, this measurement is not trivial.

If we measure a black character stroke on a white screen (such as Fig. 1), and we do not compensate for veiling glare, we may obtain an incorrect contrast ratio that may be far less than the actual small-area contrast ratio. This could lead to making incorrect estimates of the performance of the display, setting poor conformance standards, and developing erroneous conclusions about the human visual system.

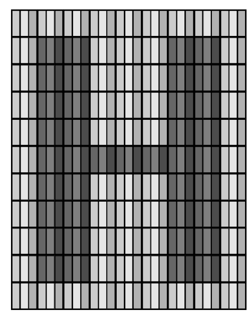

Figure 1. Typical black luminance measurement pattern.

Replica Mask

Since the glossy black cone mask is not effective for measuring small-area black luminance, another mask can be utilized. This mask, called a replica mask, is a piece of black material that has the same dimension as the area that we want to measure. If the screen is rugged, the mask is placed on the display screen in close proximity to the pixel surface (see Fig. 2). If we assume that the replica mask is absolutely black, then any luminance measured from this mask is the veiling glare contribution. This contribution can then be subtracted from the measured value of the display image to obtain a more accurate measurement of the

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true luminance. That is, for a given black pixel area, A_p, the corrected measured black luminance is

$$L_b^{'} = L_b - L_g \quad (1)$$

where L_b is the luminance of the black pattern (without glare correction) and L_g is the luminance contribution resulting from veiling glare (the measured replica luminance).

Two typical patterns are shown in Fig. 3: a 4×4-pixel square and a 1-pixel line, with their associated replica masks. These patterns were among several placed on a 12.1-inch (307-mm) active-matrix liquid-crystal display (AMLCD) laptop display. The figure also shows a neutral density filter (NDF), which serves as a check of the replica mask measurements. The filter and replica mask must be the same size as the black pixel area being measured.

The square masks were cut from opaque glossy black plastic (approximately 0.25 mm thick), although other black material may be used. Glossy material was preferred due to its ability to reduce diffuse reflections from the surrounding environment. Care was taken to avoid any specular reflections off the glossy surface. The line replica mask was created using black thread; nylon, human hair, horsehair, thin wire, pencil "lead," or fine striping tape (darkened with a black marker if the material is not sufficiently black) can also be used.

We attached the masks either with pin-size drops of white glue or very tiny strips of double-stick tape on the corners. In this case, the screen used was rugged enough avoid sustained damage from the adhesive. The masks were carefully placed to avoid smearing the adhesive in such a way as to affect the reflection or transmission of the mask. Sufficient separation between the black pixels, replica mask, and filter were maintained so their presence did not affect each other -- a problem that varies with the size and shape of the patterns.

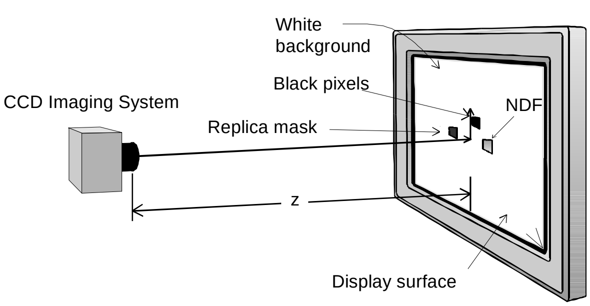

Figure 2. Measurement configuration.

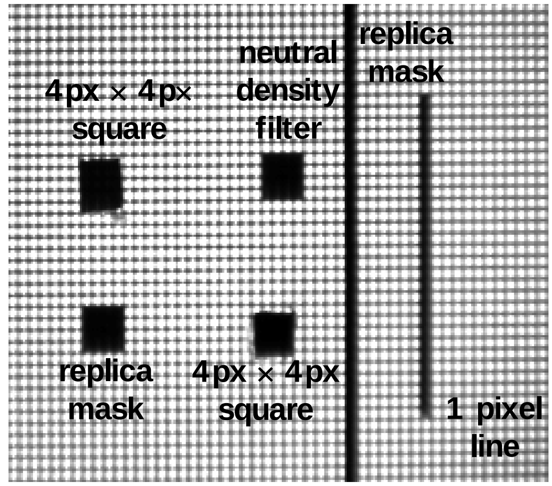

Figure 3. Patterns and masks for small-area black luminance measurements.

Check Standard

To verify that the luminance of the replica mask did indeed represent the veiling glare contribution, we measured a mask of the same size constructed from a calibrated plastic NDF film (see Fig. 3). These measurements were taken at the same time as the black luminance measurements were made to serve as a check. The filter had a measured attenuation of approximately 80:1. In all cases, we were able to measure the transmission of the filter correctly (to within 5%) once the veiling glare contribution was subtracted out (see Table 1). If the NDF transmission

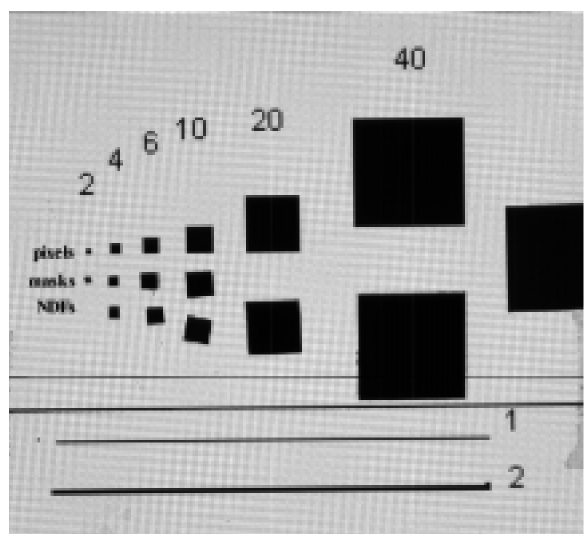

Figure 4. Patterns and masks for small-area black luminance measurements (numerals indicate the width of the pattern in number of pixels). Note that these black areas are too close together for accurate measurements. We show them for illustration purposes.

measurement were incorrect, the other measurements would be suspected as well. Thus use of these filters serves as a good diagnostic and is recommended.

These films exhibited a temperature coefficient, so we monitored the temperature of the display screen surface. To obtain a relative calibration of the filter, we waited until the screen temperature had stabilized. Then we measured the transmission of a large piece of the filter material placed on the display with a glossy cone and the light-measuring device. We measured this filter after every series of measurements to verify that the filter transmission had not shifted.

Measurements

We measured black patterns of increasing size (see Fig. 4): a single-pixel line, a 2×2-pixel square, a 4×4-pixel square, a 6×6 pixel square, a 10×10-pixel square a 20×20-pixel square, and an 11×11-checkerboard pattern, and calculated the contrast ratio, C_R. The following formula was used:

$$C_R = \frac{L_w}{L_b} \quad (2)$$

for the uncorrected contrast ratio, and

$$C_R^{'} = \frac{L_w}{L_b^{'}} \quad (3)$$

for the contrast ratio corrected for veiling glare, where L_w is the luminance of the white background measured near the black patterns.

Results are listed in Table 1 and plotted in Fig. 5. For each pattern size, we found a significant improvement in the contrast measurement when corrected for glare using the replica mask. A larger 11×11-checkerboard pattern, using a glossy black cone,

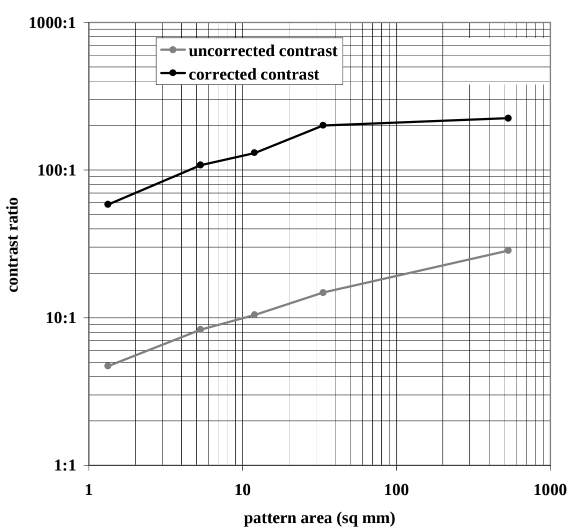

Figure 5. Effect of veiling glare on measurement of contrast.

was used to verify the replica mask measurement (see Table 2). The cone has been shown to be an improved method of eliminating the effects of veiling glare [2].

The one-pixel line was measured with a 512 x 512 scientific-grade thermoelectrically cooled, photopic charge-coupled device (CCD) camera, which was attached to a long-distance microscope. We chose this apparatus in order to achieve good magnification. The remaining patterns were measured with the CCD only, with a 200-mm lens at f/22 and f/8. The image consists of three types of patterns: the pixel patterns, the replica masks, and several NDFs as checks. As seen in Fig. 5, the improvement of the contrast measurement using replica masks is on the order of 10 or more over the traditional method.

Table 1. Effect of veiling glare on small-area contrast measurements.

Pattern	Uncorrected small-area contrast	Corrected small-area contrast	Corrected NDF
1-pixel line	8:1	122:1	-
2×2-pixel line	5:1	58:1	-
4×4-pixel square	8:1	108:1	79:1
6×6-pixel square	11:1	130:1	79.1
10×10-pixel square	15:1	200:1	77:1
20×20-pixel square	28:1	225:1	81:1
11×11 checkerboard	50:1	265:1	81:1

Table 2. Comparison of replica mask method with cone mask method for measuring the contrast of an 11×11-checkerboard pattern.

Mask type	Uncorrected small-area contrast	Corrected small-area contrast	Corrected NDF
Replica mask	49:1	262:1	81:1
Cone mask	-	261:1	81:1

Fragile Surfaces

Many displays do not allow for masks to be placed directly onto the screen surface. For this situation, an alternative method is recommended using a simulated screen. Several possibilities include using a piece of

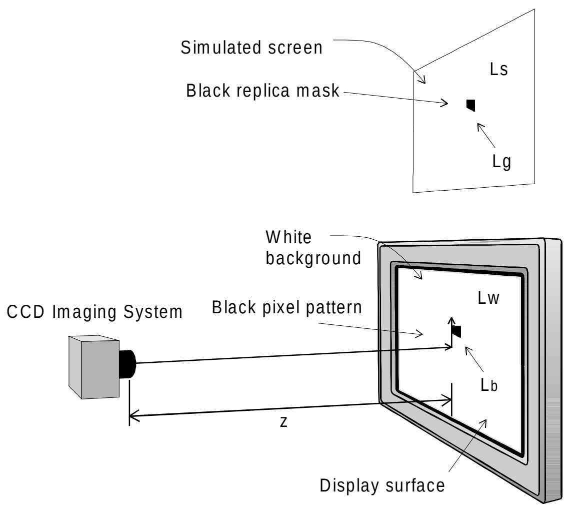

Figure 6. Measurement configuration with simulated screen.

glass placed in front of (but not touching) the screen, a rugged laptop computer display the same size as the screen under test, or a cathode-ray tube (see Fig. 6). The simulated surface should appear relatively uniform, and have the same luminance as the display surface. This method was not evaluated for this paper, but is offered as a suggestion.

To implement this method, place the replica mask on the simulated screen surface, and measure the black luminance of the mask L_g and the white luminance of the simulated screen L_s. Obtain similar measurements for the black luminance of the pixel image L_b and the white luminance of the display screen L_w. The corrected black measurement would then be:

$$L_b^{'} = L_b + L_g \left(\frac{L_w}{L_s} \right). \quad (4)$$

Errors

The variation in the corrected small-area contrast (see Table 1) may be explained by the fact that the smaller the mask, the more susceptible it is to imperfections associated with the mask, the lens system, and imperfections in the CCD system. It is important to provide sufficient magnification for the smaller objects, or defects in the system can degrade the measurement. A minimum of ten detector pixels per display pixel, preferably twenty or more, is recommended. This is why having an NDF mask provides a good diagnostic.

Additionally, the veiling glare is not uniform across the mask, so the correction can depend upon the size of the area selected to measure in the black regions. However, this method provides for a far better measurement of the small-area black luminance level of the display.

The non-linearity and the non-uniformity of the CCD are better than 1%. The combined standard uncertainty of the black measurement, with a coverage factor of 2, is determined to be at least 20%. That is a vast improvement over 1000% possible without correction.

Conclusion

When performing black luminance measurements on a white screen, veiling glare can severely corrupt the luminance measurement unless proper precautions are made. Careful use of replica masks can significantly compensate for the glare contribution, providing for a more accurate indication of display contrast.

It is always useful to test our metrology using well-thought-out diagnostics, and, if the particular metric is shown to be inadequate, to develop alternatives. If uncorrected data is used to set conformance standards, erroneous conclusions can be made.

For instance, based on our uncorrected measurements, a 4×4-pixel square produced a contrast ratio of 8:1, whereas the corrected measurements produced a contrast ratio of 108:1. If the uncorrected value is used in evaluating character recognition, then incorrect claims could be asserted concerning the human visual system. One could contend that since they measure only 8:1, that this the contrast appreciation level of the eye for small areas. But, as our data shows, the black luminance levels can be much lower if correctly measured. Without diagnostics, how do we know if the problem is with the equipment or the eye? We should not compromise good metrology in favor of tradition, especially if that tradition might be based upon inadequate metrology.

References

[1] H. S. Coleman, “Stray Light in Optical Systems,” J. Opt. Soc. Amer., vol. 37, no. 6, June 1947, pp. 434-451.

[2] P. A. Boynton and E. F. Kelley, “Accurate Contrast Ratio Measurements Using a Cone Mask. SID Int’l Symp. , Boston, MA, May 11-16, 1997, vol. XXVIII, pp. 823-826. (May 1997)